LABORATOIRE ÉLECTRONIQUE, SYSTÈMES DE COMMUNICATION ET MICROSYSTÈMES

Sous la co-tutelle de :
CNAM
ESIEE PARIS
UPEM • UNIVERSITÉ PARIS-EST MARNE-LA-VALLÉE

A new method and transceiver architecture dedicated to continuous detection of very small metallic object

Pape Sanoussy DIAO

Team : RF, mm and optics systems
Theme: Low-power architectures and associated processes

Thesis director : Martine VILLEGAS
Supervisors : Benoit POUSSOT & Thierry ALVES

Copyright

Abstract

In this work, we propose a multi-band impulse detection technique to improve the detection of small objects. The choice of frequency bands is based on millimeter ultra-wideband (UWB) normalization and is related to the radar cross section of the objects to be detected. A nomadic impulse architecture associated with the detection principle is proposed. By using two orthogonal polarizations, our results show that multi-band impulse method offers better performances in terms of continuous detection surface compared to conventional single band detection system.

Index Terms: *UWB, Millimeter wave, Impulse mode, RCS, Continuous object detection, Differential architectures*

Biography

Pape Sanoussy Diao was born in 1991 in Kounkané (Sénégal). He received the M.S. in Electronics Telecommunications and Geomatics, speciality High Frequency Communication Systems from Université Paris-Est Marne-la-Vallée, France, in 2015.

Currently he is doing a PhD in Electronics, Optronics and Systems at Université Paris-Est at ESYCOM laboratory in ESIEE Paris. He works on the theme *Low-power architectures and associated processes* under the direction of Professor Martine VILLEGAS and under the supervision of Dr Benoit POUSSOT and Dr Thierry ALVES. His is particularly interested in *RF systems, Architectures and mm-wave technologies*.

Outline

- Introduction
- Principle of detection and Radar cross section
- Dual-band and dual-polarization approach
- Dedicated architecture
- Processing and decision
- Results and comparisons
- Conclusion and outlook

Introduction (1)

- Context
  - Security Challenges and Surveillance
  - Increasing need for detection and localisation systems

X-ray scanner
SURETECH

Active body scanner
Rohde&Swartz

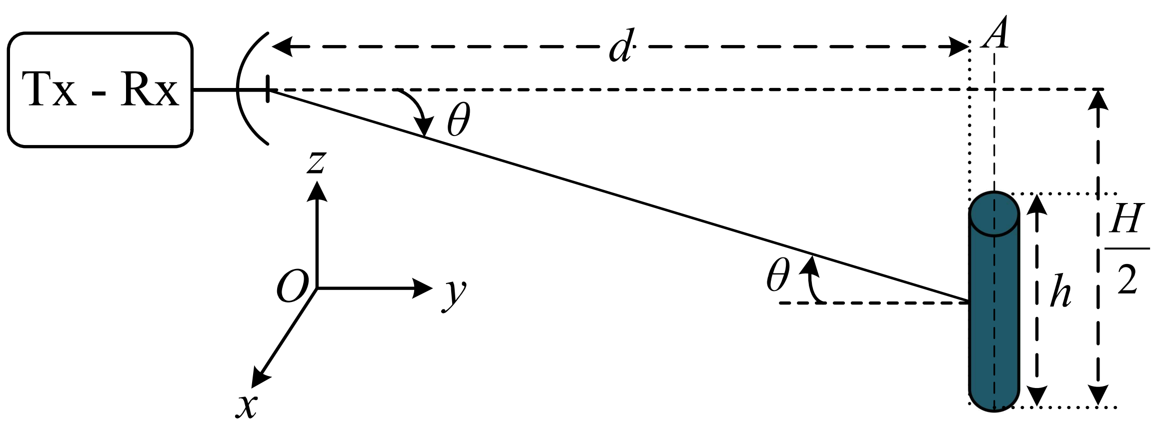
Passive body scanner
MC2 technologies

Introduction (2)

- Goals
  - Propose a nomadic system for objects’ detection
    - miniature & low power consumption
  - Detect small metallic objects
    - Lager dimension < 10 cm
  - Improve detection performances
    - Maximize detection range
    - Increase detection coverage

Introduction (3)

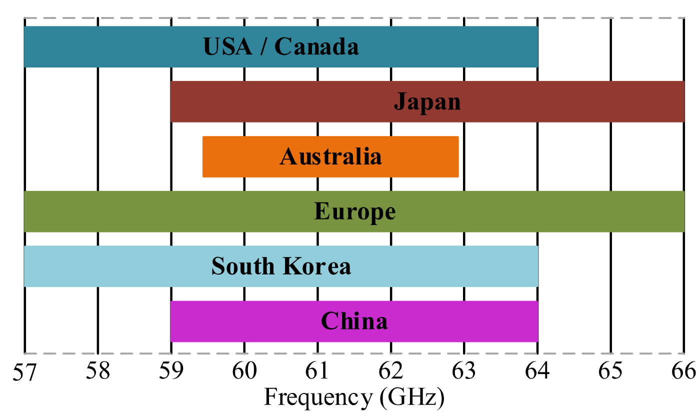
- Scenario
  - Monostatic configuration
    - Co-located antennas
    - Antenna aperture ~ 60° in E plan
  - In free space
  - Static cylindrical metallic target (radius *r* ; height *h*)



Principle of detection

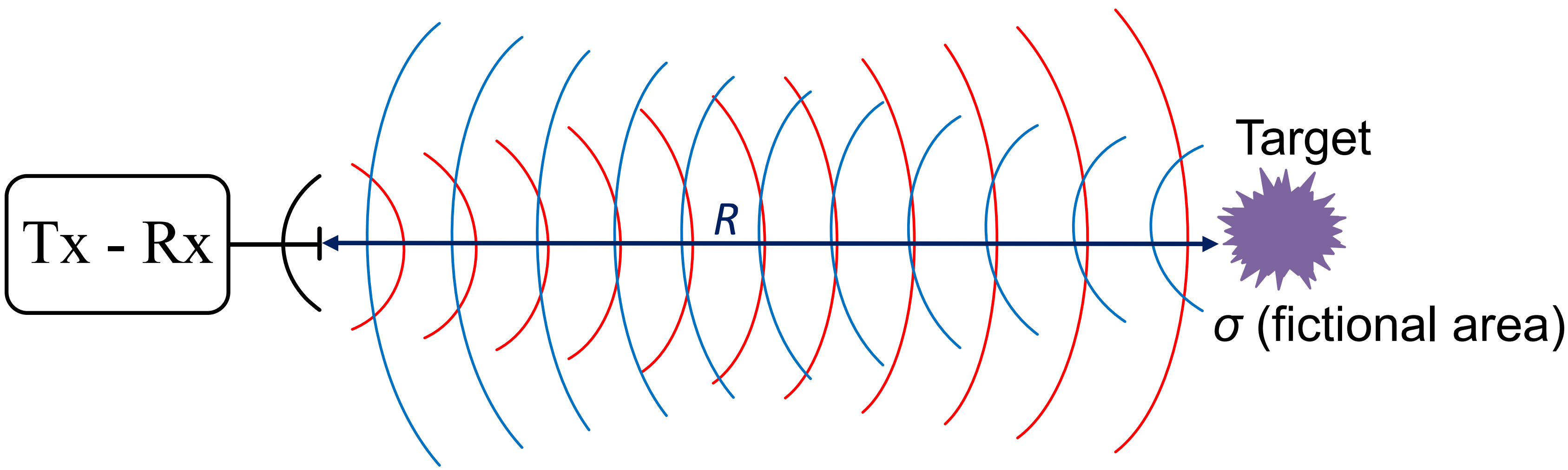
- Impulse method
  - Easy and simple to implement
- Ultra Wide Band (UWB)
  - Short pulse : high resolution, accuracy
- Millimeter wave frequencies
  - Short λ : small targets detection
- UWB @60 GHz
  - Potential solution
  - Spectrum availability

Unlisenced bands



Radar cross section (1)

- Radar cross section (RCS)



- Expression

$$\sigma = \lim_{R \to \infty} 4\pi R^2 \left| \frac{E_r}{E_i} \right|^2$$

E_i : incident electric field

E_r : reflected electric field

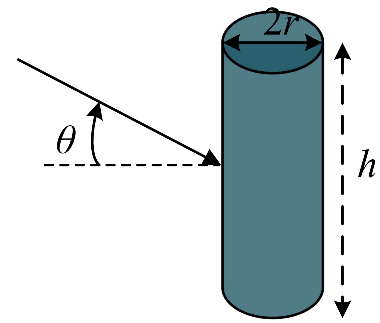
R : distance in (m)

σ in (m^2)

Radar cross section (2)

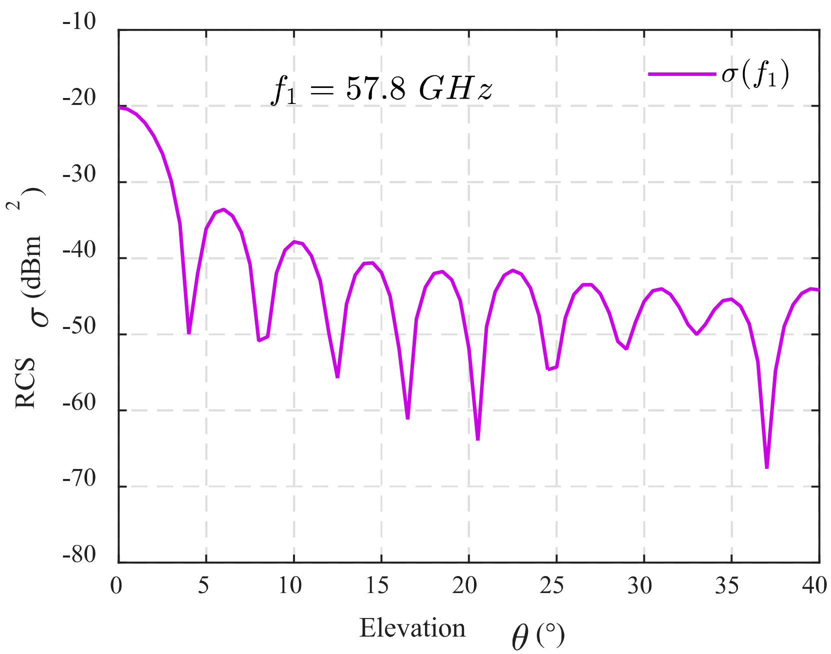
- Simulation model : HFSS

θ : angle of incidence



- Monostatic RCS variation

Cylinder (r = 5.2 mm ; h = 3.6 cm)



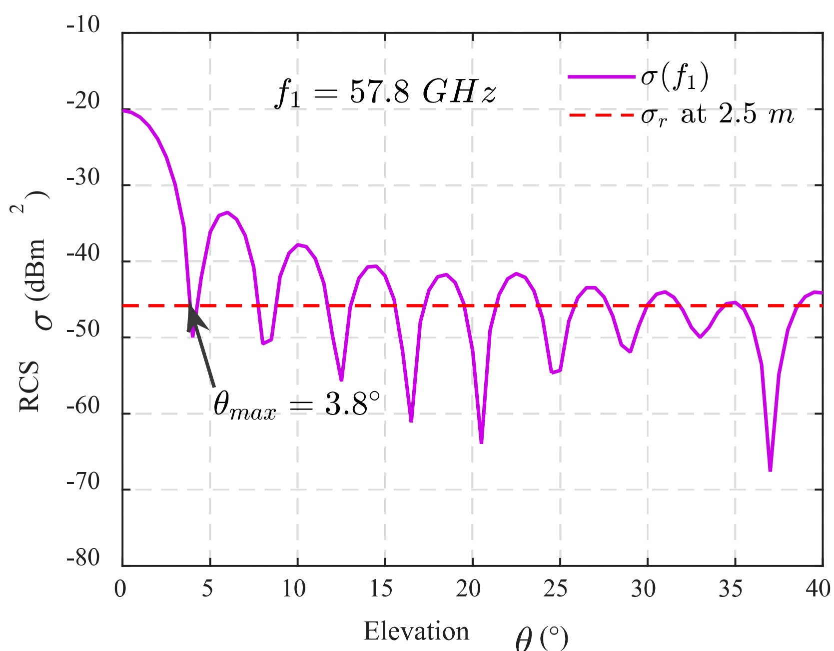
Radar cross section (3)

- Required RCS $\sigma_r = f\,(f, d, SNR_r)$
- Required SNR
  - $SNR_r = f\,(P_D, P_{FA})$

P_D : detection probability

P_{FA} : false alarm probability

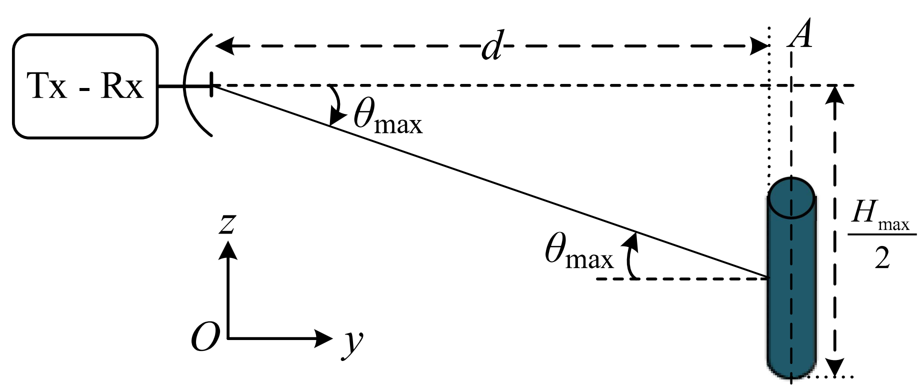
Cylinder (r = 5.2 mm ; h = 3.6 cm)



$P_D = 90\%$

$P_{FA} = 10^{-4}$

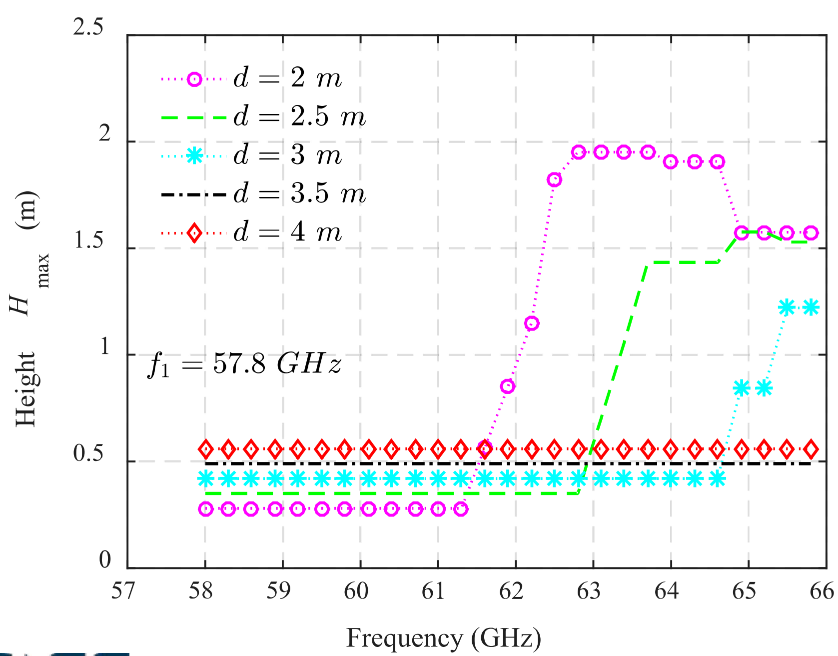
$SNR_r = 12$ dB



Dual-band approach (1)

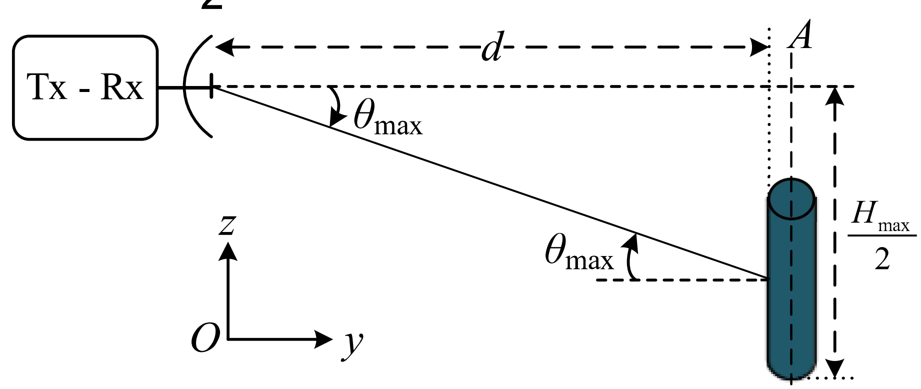
- Improve detection coverage :
  - Use a second frequency f_2
- Optimal selection of f_2
  - Maximum continuous detection height H_{max}

Cylinder (r = 5.2 mm ; h = 3.6 cm)



Target sizes : h = [3.6 cm - 7.8 cm]
Normalization : unlisenced band in Europe [57 - 66] GHz

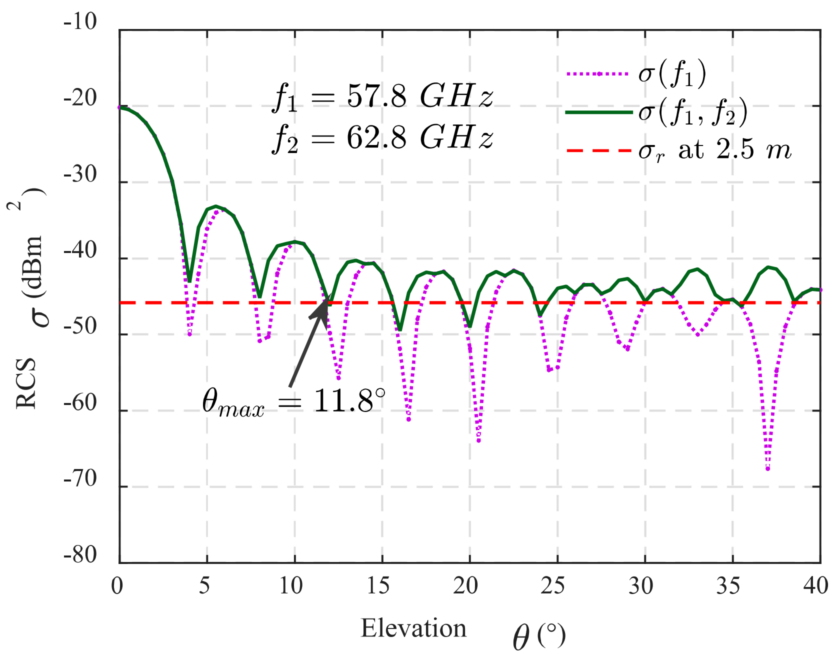
➡ f_2 = 62.8 GHz



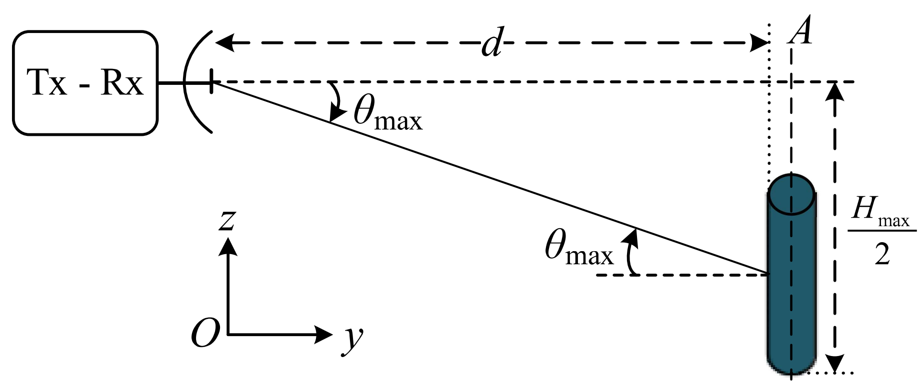
Dual-band approach (2)

- Illustration
  - Improvement of the maximum continuous detection angle θ_{max}
  - Increase maximum continuous detection height H_{max}

Cylinder (r = 5.2 mm ; h = 3.6 cm)

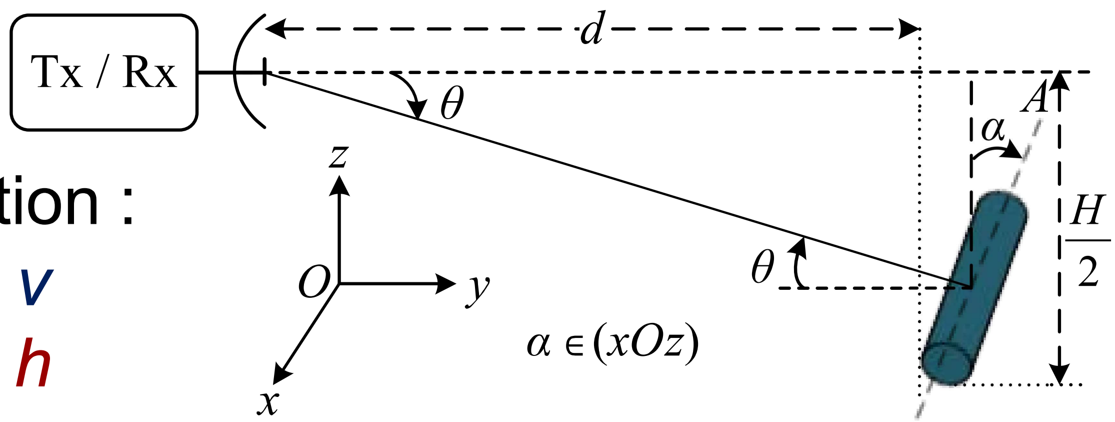


Compensation of the RCS minima by selection combining (SC) the RCS at f_1 & f_2 ➡ increase θ_{max}



Dual-polarization approach

- Target orientation



Polarization :

Polar *v*

Polar *h*

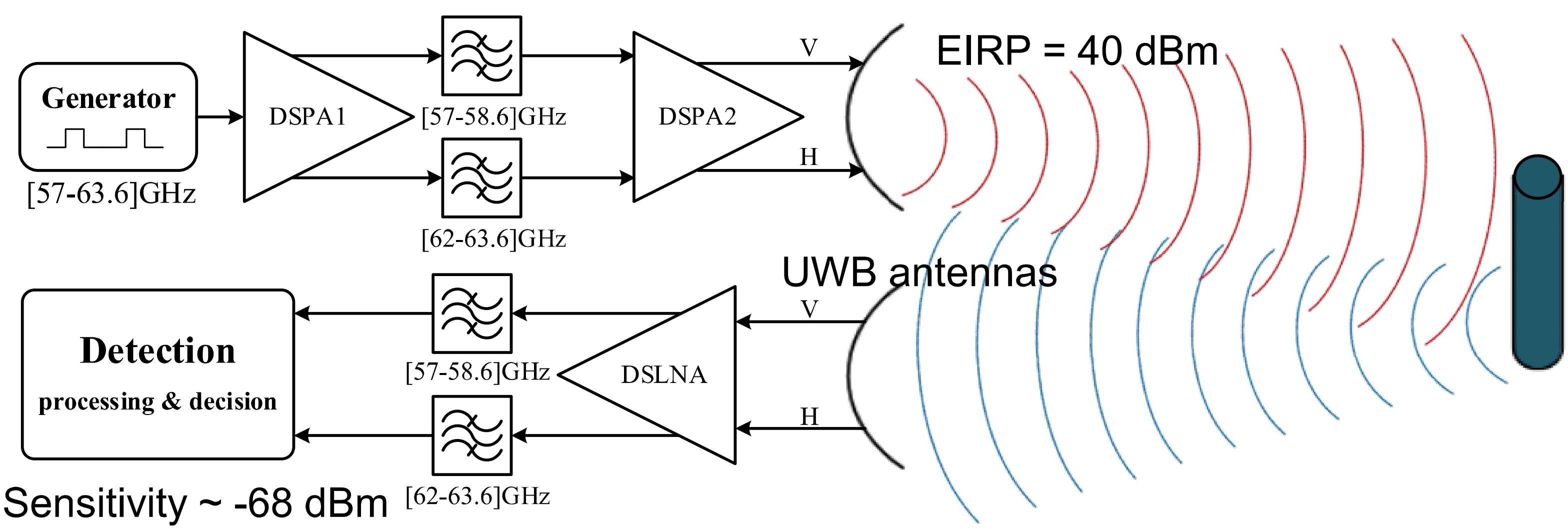
- Optimal polarization of the bands

h = [3.6 cm - 7.8 cm] and α = 0°, 20°, 40° & 60°

  - Single band (f_1) : *h*
  - Dual-band (f_1, f_2) : *vh*

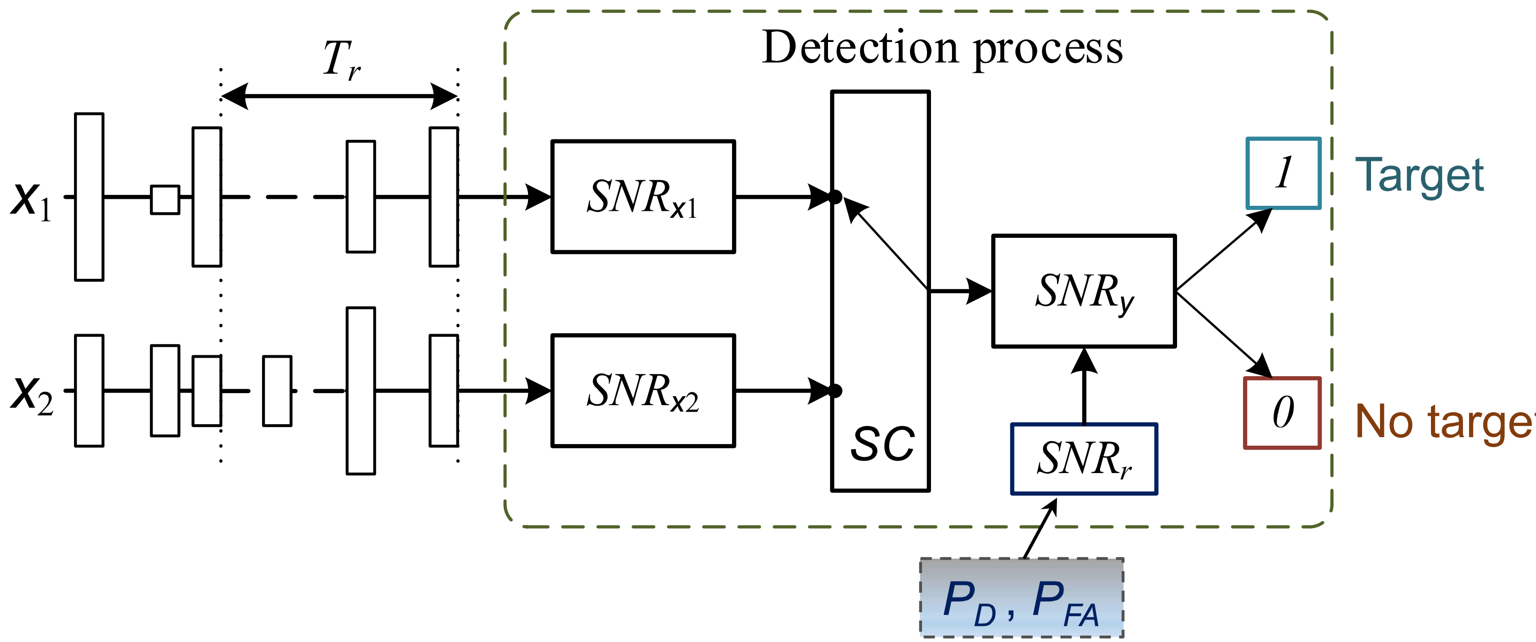
Dedicated architecture

- Broadband Generator
  - Pulse repetition period T_r
- Filter bank : BW = 1.6 GHz
- Differential structure power amplifier (DSPA)
- Differential structure low noise amplifier (DSLNA)



Processing and decision

- SNR calculation on each branch : SNR_{x1} & SNR_{x2}
- Selection combining (SC)
  - $SNR_y = \max(SNR_{x1}, SNR_{x2})$
- Comparison : SNR_y & SNR_r

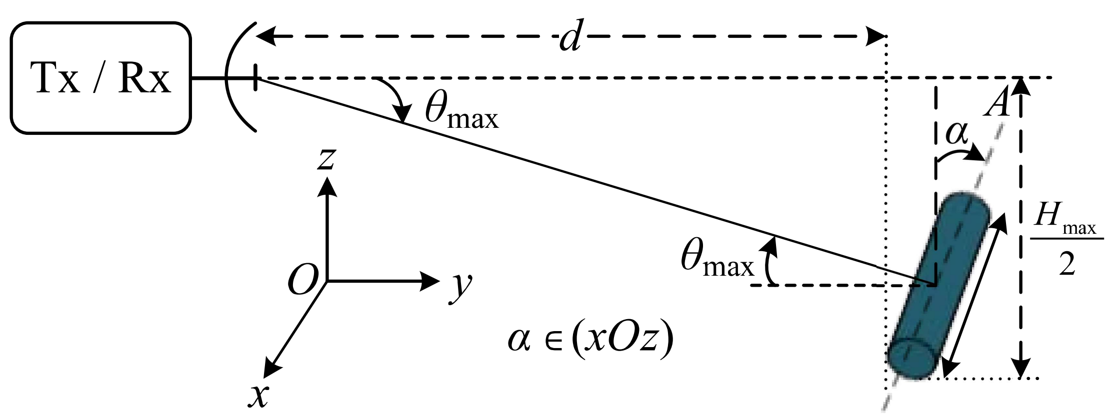


Results and comparisons (1)

- Assessment method
  - For each distance *d*, determine θ_{max} (continuous detection)
    - For any $\theta \leq \theta_{max}$, $\sigma \geq \sigma_r$
  - Determine $H_{max} = f(\theta_{max}, d)$ (continuous detection)

$$H_{max}/2 = d\tan(\theta_{max}) + h/2$$

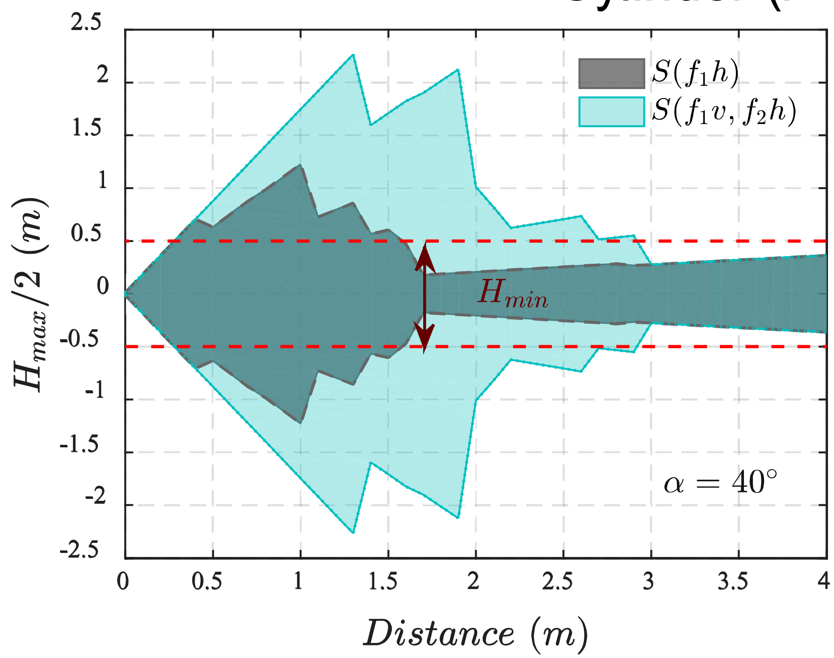
  - Calculate continuous detection surface
    - $S = f(H_{max}, d)$ in the *yOz* plan

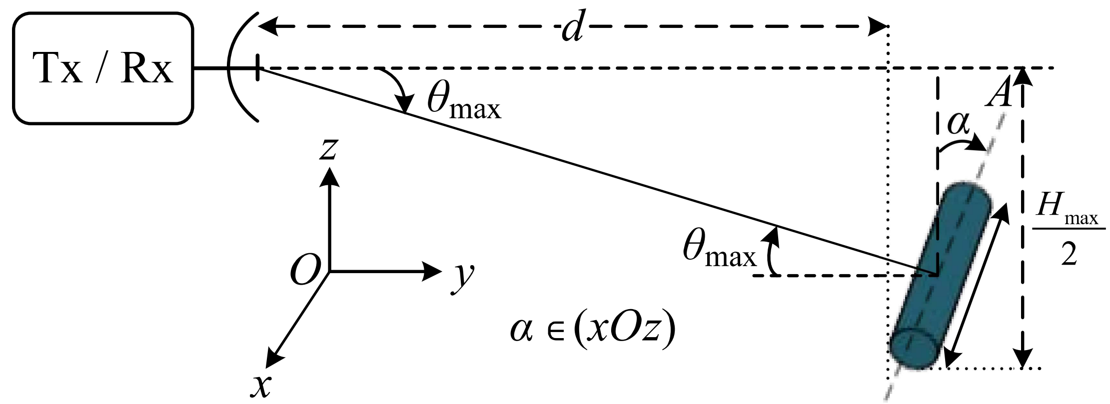


Results and comparisons (2)

- Comparison: single band / dual band

Cylinder (r = 5.2 mm ; h = 3.6 cm)





Continuous detection range R_{max} over 1 m

$R_{max}(f_1\ h)$ = 0. 3 - 1.6 m

$R_{max}(f_1\ v, f_2\ h)$ = 0.3 - 2.9 m

Continuous detection surface

$S(f_1\ v, f_2\ h) = 1.9S(f_1\ h)$

Approach	α = 0°	α = 20°	α = 40°	α = 60°
Single band f_1 h	R_{max} = 0.3 - 2.0 m S_1	R_{max} = 0.3 - 1.9 m S_2	R_{max} = 0.3 - 1.6 m S_3	R_{max} = 0.3 - 1.9 m S_4
Dual band f_1 v, f_2 h	R_{max} = 0.3 - 2.8 m S = 1.5S_1	R_{max} = 0.3 - 2.8 m S = 1.8S_2	R_{max} = 0.3 - 2.9 m S = 1.9S_3	R_{max} = 0.3 - 2.8 m S = 2.1S_4

S: Continuous detection surface

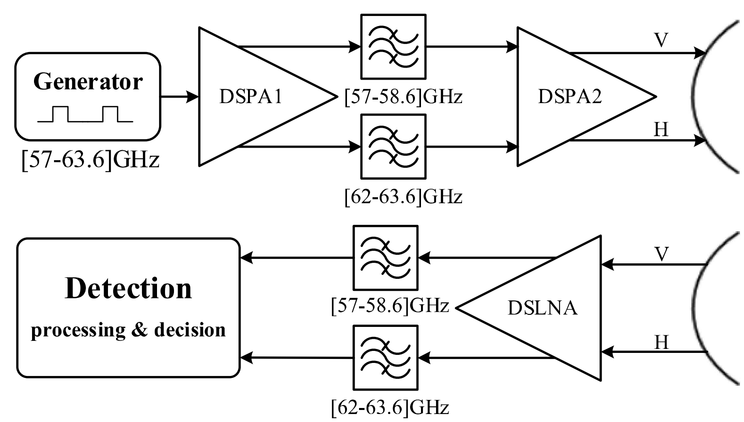
Conclusion

- Dual band - dual polarization approach
  - Improve continuous detection range
  - Increase of continuous detection surface
- Architecture
  - Simple implementation
    - No synchronisation
    - No frequency conversion
  - Compact size with DSPA and DSLNA
  - Simple processing without ADC converter
    - Low power consumption

Outlook

- Dual band - dual polarization approach
  - Validate the principle by measurements
  - Improve performances by using integration techniques

- Architecture
  - Filter bank validation: already done [1]
  - Validate critical bloc: DSPA
  - Antenna design and realization
  - Implement the detector



[1] R. Abdaoui, M. Villegas, G. Baudoin, A. Diet, "Microstrip band pass filter bank for 60 GHz UWB impulse radio multi band architectures," IMWS, IEEE MTT-S International, pp. 192-195, Sept. 2011.

References

[1] D. K. Barton, Frequency Agility and Diversity, Radars volume 6, Artech House, pp.121-126, 1977.

[2] M. Skolnik, Introduction to Radar Systems, McGraw Hill, pp. 24-33, 1980.

[3] R. Abdaoui, M. Villegas, G. Baudoin, A.S. Penaloza, “Performance assessment of a transceiver architecture based on millimeter wave multiband impulse mode”, IEEE GSMM conference, Apr. 2010.

[4] V. Ravenni, G. Pizziol, “Frequency Diversity Radar System: Design, Analysis and Performances,” Proceedings of the 3rd European Radar Conference (EuRAD), Manchester UK, pp. 221-224, Sep. 2006.

LABORATOIRE ÉLECTRONIQUE, SYSTÈMES DE COMMUNICATION ET MICROSYSTÈMES

Sous la co-tutelle de :
CNAM
ESIEE PARIS
UPEM • UNIVERSITÉ PARIS-EST MARNE-LA-VALLÉE

Thank for your attention

Pape Sanoussy DIAO

PhD student : ESYCOM Lab. / ESIEE Paris
pape-sanoussy.diao@esiee.fr